APPENDIX D

Spawning Habitat Evaluation

TECHNICAL MEMORANDUM

Spawning Habitat Evaluation

PREPARED FOR: Upper Yuba River Studies Program

PREPARED BY: Neil Nikirk, CH2M HILL/SAC
Carl Mesick, U.S. Fish and Wildlife Service

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Introduction

The adequacy of spawning habitat above Englebright Dam is an important consideration in evaluating the feasibility of introducing Chinook salmon and steelhead to the upper Yuba River. Accordingly, members of the habitat study team inventoried spawning habitat and conditions in the upper Yuba River watershed to document the location, extent, and quality of potential spawning areas. This technical memorandum describes the methods used to identify potential spawning habitat and the criteria for determining the quality of that habitat. It also presents results of the spawning habitat inventory, including the location and quality of potential spawning habitat in the upper Yuba River, and the number of Chinook salmon and steelhead redds that could be supported in the study area.

Characteristics of Salmonid Spawning Habitat

Both Chinook salmon and steelhead typically spawn at the downstream end of pools. Although other areas may occasionally be used for spawning (for example, shallow runs and pool heads), pool tails with adjacent deep water for refuge represent the most likely spawning areas (Barnhart 1991, CDFG 1998). Spawning habitat for Chinook salmon and steelhead include the following key characteristics:

- Adjacent pool habitat with sufficient depth to provide refuge
- Gravel small enough to be moved by the fish during redd construction
- Sufficient depth of suitably sized gravel
- A minimal amount of fine particles that would otherwise suffocate or entomb developing eggs and alevins in the redd
- Sufficient depth and flow of water (velocity) over the gravel bed
- Clean (non-turbid) intragravel flow
- Cool water temperatures

Assessment Approach

The habitat study team initially identified locations of potential spawning habitat for Chinook salmon and steelhead through low-altitude aerial videography taken in October 2002. The initial examination of the aerial video indicated that there were over 400 potential spawning sites with areas of suitably sized gravel at the pool tails. However, under even the best of circumstances, the video images were not sharp enough to allow the viewer to differentiate among individual particles of gravel smaller than about 38 millimeters (mm) (1.5 inches) in diameter. In addition, shadows and blurry images made it particularly difficult to discern substrate sizes at approximately 10 percent of the sites. To help calibrate the estimates of gravel size from the video images, the team conducted field surveys at 101 sites adjacent to public access points in the South Yuba and Middle Yuba rivers in July 2003 (Figure 1).

The team also conducted field surveys in the lowermost reaches of Canyon and Poorman creeks (two tributaries to the South Yuba River) and the lowermost reaches of three tributaries to the Middle Yuba River (Oregon, Kanaka, and Wolf creeks). None of the five tributaries surveyed had spawning habitat that was suitable for Chinook salmon and steelhead. Although Poorman Creek on the South Yuba River and Kanaka and Wolf creeks on the Middle Yuba River have small patches of suitably sized gravel, none of the gravel patches had nearby pool habitat preferred by adult Chinook salmon and steelhead. Neither Canyon nor Oregon creeks had suitably sized gravel near their confluence with the main rivers. A small dam located near the mouth of Canyon Creek prevents upstream migration of fish from the South Yuba River.

Median Gravel Size

At 40 of the 101 potential spawning sites visited during the field surveys, the median diameter of the gravel (d_{50}) in the primary spawning area was first visually estimated and then measured using the Wolman pebble count methodology (Wolman 1954, Kondolf 2000). These side-by-side comparisons indicated that the team was able to accurately visually estimate gravel sizes in beds where the median diameter was about 25 mm (1 inch), but they usually overestimated the size of gravels in beds by about 50 percent where the true median diameter was 50 mm (2 inches) or more. The following statistical relationship between visual estimates and measured gravel size was developed to correct for this bias:

$$\text{Measured } d_{50}\text{ (mm)} = 0.487 \times \text{Visually Estimated } d_{50}\text{ (mm)} + 16.139$$
$$[R^2 = 0.66,\ p = 0.000]$$

The correction was applied to visual estimates that were made at the remaining 61 sites during the field surveys. Median gravel sizes estimated from the aerial video at the remaining unsurveyed sites were not adjusted.

Habitat Quality and Quantity

The team assessed gravel quality at the potential spawning sites by measuring streambed permeability at 3 to 6 points in the gravel bed of 31 potential spawning sites in the South Yuba and Middle Yuba rivers. Permeability measurements were taken by driving a standpipe (Barnard and McBain 1994) into the gravel bed until perforations near the tip of the pipe were at a substrate depth of 30 centimeters (cm) (12 inches) when possible, and using a battery-powered vacuum pump to measure the rate that water could be pumped from the pipe. To simulate the loosening effect of redd construction and focus the permeability measurement on the presence of fines and intragravel water flow, the gravel was loosened by rocking the standpipe back and forth in the substrate prior to taking the permeability measurement.

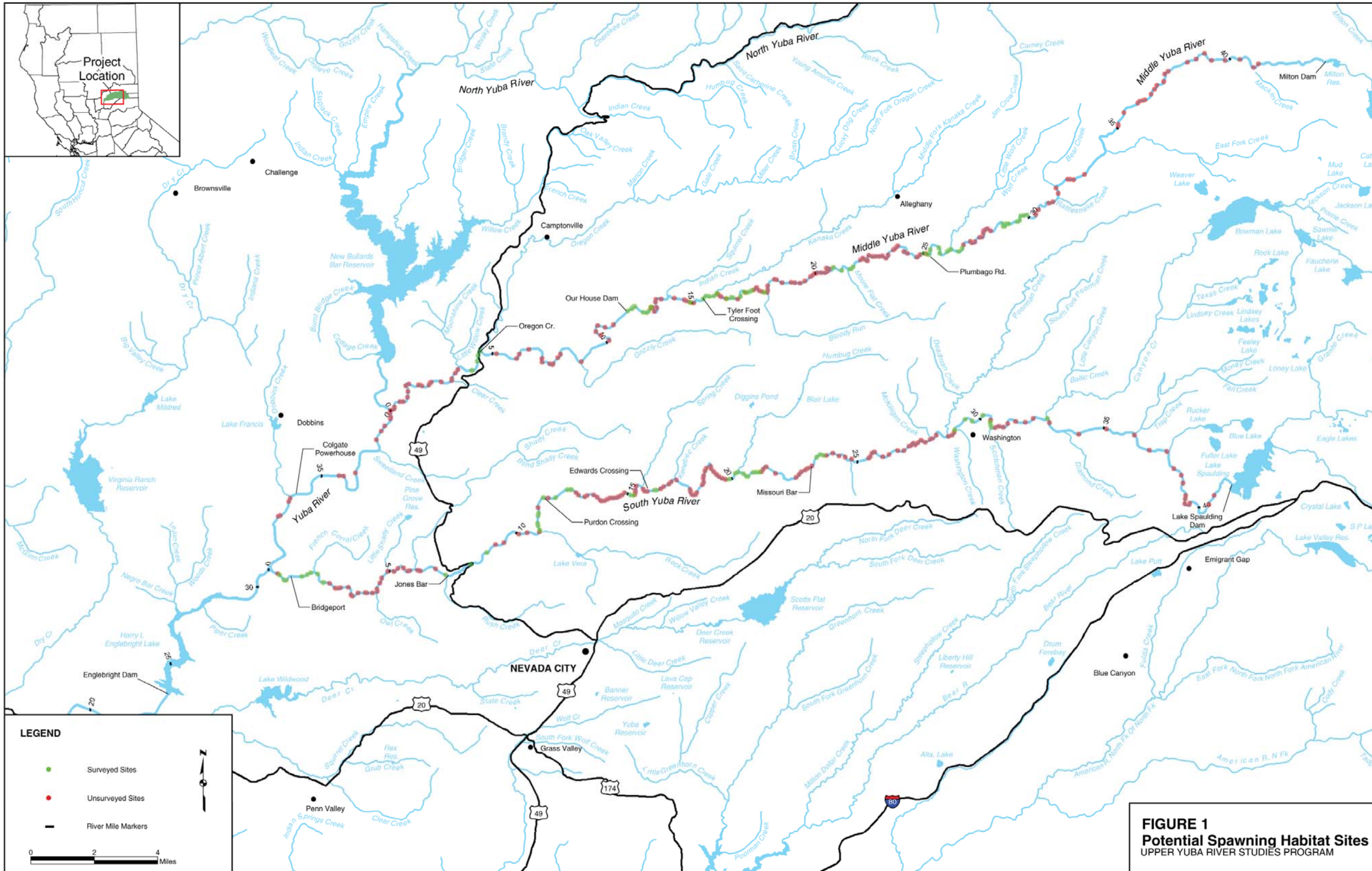

FIGURE 1
Potential Spawning Habitat Sites
UPPER YUBA RIVER STUDIES PROGRAM

To further assess potential spawning habitat quality and quantify the aerial extent of potential spawning gravels, additional measurements were taken during the intensive surveys at 31 sites in the Middle Yuba and South Yuba rivers that included: (1) the area and depth of suitably sized gravel in the wetted channel and floodplain; (2) the depth and velocity of the water flowing over the spawning-sized gravel; (3) the maximum depth of the water in nearby pool habitat; and (4) whether cover provided by undercut boulders, overhanging vegetation, or surface turbulence was present in the nearby pool habitat.

These data were then used to estimate the area of usable gravel, the presence of cover, and maximum pool depth in the other potential spawning habitat sites as viewed in the low-altitude videography. Adjacent pool habitat was judged to provide suitable refuge for Chinook salmon during autumn low flows if the depth of water in the pool was at least 2.4 meters (8 feet), or if the pool depth was between 1.2 and 2.4 meters (4 and 8 feet) and boulders, overhanging vegetation, and/or surface turbulence were present to provide cover. When the maximum depth of the adjacent pool habitat was less than 1.2 meters (4 feet) or cover was not present, sites were considered to provide suitable spawning habitat only for steelhead.

Potential Number of Redds

Based on the area of potential spawning habitat observed in the upper Yuba River watershed, the potential number of Chinook salmon redds and steelhead redds that could be supported was estimated using a regression equation developed for fall-run Chinook salmon in the lower Stanislaus River (CMC 2001, 2002a, 2002b). This relationship is based on (1) adjusted maximum fall-run Chinook salmon redd densities in the lower Stanislaus River relative to median gravel size determined from bulk surface substrate samples, (2) relative sizes of Chinook salmon and steelhead redds, and (3) the upper size limit of gravels that can be moved by steelhead-sized fish. The relationship for fall-run Chinook salmon is based on measurements of redd density and median gravel size at 11 sites in a highly used reach of the Stanislaus River.

A majority of the redd density measurements in the Stanislaus River were made during the fall of 1998 when escapement was below average and it was unlikely that the spawning beds were saturated with redds. The redd surveys were repeated at some of the 1998 study sites and at two recently restored sites in the fall of 2000 when the salmon run was above average and presumably the habitat was saturated with redds. The redd densities in 1998 were multiplied by the ratio of fall 2000 redd densities to fall 1998 redd densities (2.1416) to estimate the maximum potential redd densities at all the Stanislaus River study sites (Table 1).

The relationship between maximum redd density and median gravel size was nonlinear with peak redd densities occurring at median gravel sizes of 20 mm. The following regression equation for Chinook salmon was developed with data collected from the 10 Stanislaus River sites where median gravel sizes were at least 24 mm:

$$\text{Redd Density (redds/100 ft}^2\text{)} = 0.0005838 \times (d_{50} \text{ in mm}) + 0.06087$$
$$[R^2 = 0.63, p = 0.004]$$

To adjust the density for sites with smaller-sized gravels, the estimates were multiplied by 0.15 and 0.65 to estimate redd densities where the median gravel size was 10 mm and 15 mm, respectively. The relationship between Chinook salmon redd density and median gravel size is shown in Figure 2.

TABLE 1
The density of Chinook salmon redds observed in fall 1998 and fall 2000, the estimated maximum number of potential redds, and the median gravel size at eleven Knights Ferry Gravel Replenishment Project study sites in the lower Stanislaus River between river mile 51.8 and 56.8.

Study Site	1998 Redd Density/ft^2	2000 Redd Density/ft^2	Estimated Maximum Redd Density/ ft^2	Median Gravel Size
TMA	0.0102		0.02189	80
TM1	0.0130	0.0298	0.02784	55
R1	0.0177		0.03784	40
R5	0.0176		0.03760	30
R10	0.0151		0.03236	15
R14	0.0130		0.02784	36
R14A	0.0030		0.00643	80
R19	0.0100		0.02142	45
R20 Main	0.0195	0.0389	0.04180	36
R12B Restored	—		0.05689	24
TMA Restored	—		0.05422	35

ft^2 = square foot

The availability of adjacent pool habitat with cover can affect the use of otherwise suitably sized gravels by Chinook salmon. It was assumed that sites with pool depths between 1.2 and 2.4 meters (4 and 8 feet) and only a small amount of cover were less suitable for Chinook salmon spawning and would support a lower number of Chinook salmon redds than sites with an abundance of cover or adjacent pool depth that was greater than 2.4 meters (8 feet). Accordingly, the estimated number of Chinook salmon redds at these sites was multiplied by 0.5 to account for the lower suitability. Sites where adjacent pool habitat was shallow (less than 1.2 meters [4 feet]) or where no cover was present were considered unsuitable for spawning by Chinook salmon.

A similar relationship between median gravel size and redd density was developed for steelhead by assuming that typical Central Valley steelhead (large fish are about 26 inches in length) and their redds would be 40 percent smaller than Chinook salmon (Bjornn and Reiser 1991) and that relatively few Central Valley steelhead would be able to spawn in gravel with a median diameter larger than about 66 mm (2.6 inches). To adjust for the inability of steelhead to move large gravel, the coefficient for the median gravel size was multiplied by 1.68. To adjust for the smaller redd size, the estimated number of redds was multiplied by 1.4. The equation used to estimate steelhead redd densities where median gravel sizes were at least 20 mm is:

Redd Density (redds/100 ft^2) = (-0.0005838 x 1.68 x (d_{50} in mm) + 0.06087) x 1.4

As for Chinook salmon, the estimated number of steelhead redds was multiplied by 0.15 and 0.6 to adjust redd densities for smaller-sized gravels at sites with median gravel sizes of 10 mm and 15 mm, respectively. The relationship between the estimated steelhead redd density and median gravel size is shown in Figure 2.

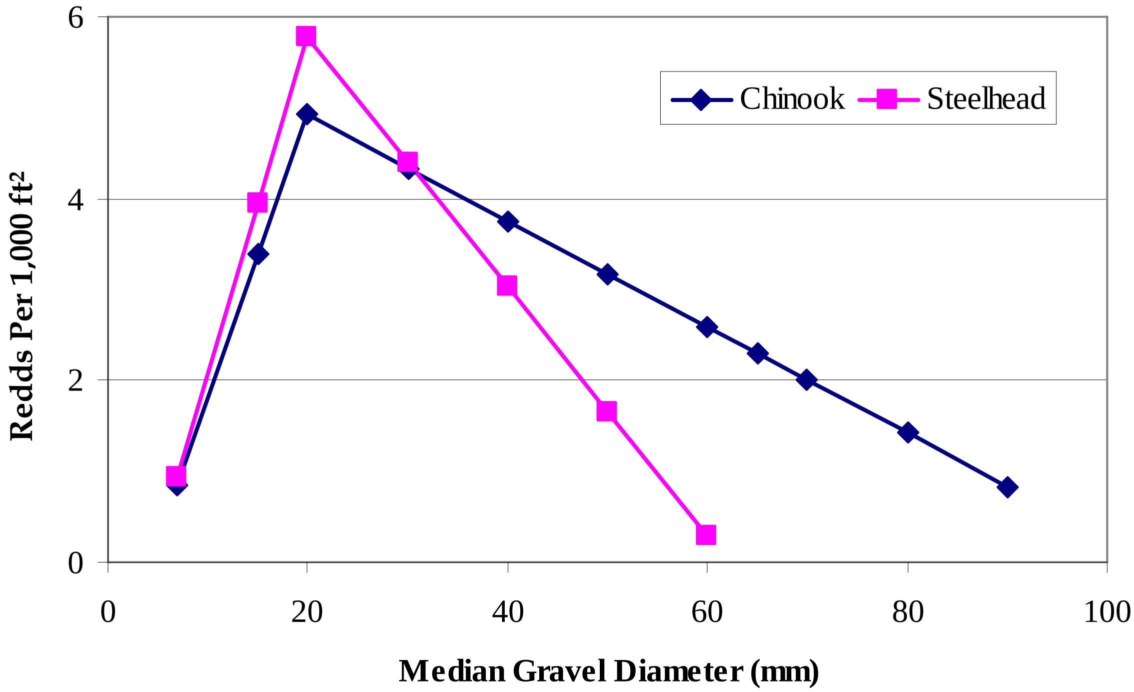

FIGURE 2
The Predicted Density of Chinook Salmon and Steelhead Redds Relative to the Median Gravel Diameter Based on Stanislaus River Studies

The stated relationships between redd densities and median gravel size reflect extremely crowded conditions where redds are superimposed on others. Redd superimposition affects the viability of eggs and alevins in previously constructed redds. Based on the Stanislaus River studies (CMC 2002b), the estimated total number of redds was adjusted downward by 17.4 percent to account for the effects of redd superimposition. Alevins can also be entombed by redd superimposition; the Stanislaus River studies indicate that up to 16 percent of redds contained alevins that were entombed as a result of superimposition in silty substrates (permeability less than 10,000 centimeters/hour [cm/hour]) (CMC 2002b). The estimated total number of redds was further reduced to account for the mortality due to entombment of alevins by multiplying estimated number of redds by an adjustment factor based on the Stanislaus River studies: 1-((1-(Ln Permeability/9.2103)) x 0.395196).

Results

Distribution of Potential Spawning Habitat in the Upper Yuba River Watershed

Based on the aerial videography and field surveys, there are approximately 415 potential spawning sites, most of which are located in the South Yuba and Middle Yuba rivers (see

Figure 1). On the Middle Yuba River, most of the potential spawning sites are located upstream of Our House Dam (River Mile [RM] 12) and downstream of Oregon Creek (RM 4); few sites exist upstream of Tehama Ravine (RM 30). On the South Yuba River, potential spawning sites are sparsely distributed from Bridgeport (RM 1) to Purdon Crossing (RM 12), with a denser concentration of sites upstream around Edward's Crossing (RM 16), Humbug Creek (RM 20), and Missouri Bar (RM 24); relatively few spawning sites exist upstream of the town of Washington (RM 29). No potential spawning sites were identified in the North Yuba River below New Bullards Bar Dam. The habitat study team identified only 13 potential spawning sites in the upper Yuba River, all of which are located downstream of the mouth of the Middle Yuba River. Most of the sites in the Yuba River below the mouth of the Middle Yuba River contained relatively large gravel (d_{50} = 45 to 60 mm [1.8 to 2.4 inches]) and would be used by only a few Chinook salmon and steelhead.

Median Gravel Size

Median gravel sizes at 21 intensively surveyed potential spawning sites on the South Yuba River ranged from 6.6 to 74.3 mm (0.25 to 2.9 inches); in the Middle Yuba River (19 sites), the median gravel size ranged from 21.4 to 64.0 mm (0.84 to 2.5 inches) (Table 2). Visual estimates of the median gravel size at the remaining sites ranged from 15 to 150 mm (0.6 to 5.9 inches) in the South Yuba River, 30 to 120 mm (1.2 to 4.7 inches) in the Middle Yuba River, and from 40 to 60 mm (1.6 to 2.4 inches) in the Yuba River below the mouth of the Middle Yuba River.

Habitat Quality

The mean bed permeability was 37,858 cm/hour and 63,090 cm/hour at 16 sites on the South Yuba River and 15 sites on the Middle Yuba River, respectively. Individual permeability measurements within sites ranged from 192 to 273,229 cm/hour (Table 3). Mean permeability was relatively low (1,318 to 6,137 cm/hour) at a total of 10 sites near Highway 49, Purdon Crossing, and Missouri Bar on the South Yuba River and near Moore's Flat on the Middle Yuba River.

At 26 of the 31 sites the habitat team surveyed intensively, the depth of the loose gravel was at least 30 cm (12 inches) deep, as determined by the ability to drive the permeability standpipe into the streambed. However, it was not possible to drive the standpipe into the streambed more than 7.5 to 18 cm (3 to 7 inches) at 5 of the sites where the median gravel size was relatively large (median gravel size between 50 and 76 mm [2 and 3 inches]).

The mean water depth over the gravel beds at the 31 intensively studied sites was 0.4 and 0.5 meters (1.4 and 1.7 feet) in the Middle Yuba and South Yuba rivers, respectively. The mean velocities were 25.9 and 21.0 cm per second (0.85 and 0.69 feet per second) in the Middle Yuba and South Yuba rivers, respectively (Table 4).

TABLE 2
Measured and Visually Estimated Median Gravel Size at Selected Sites on the South and Middle Yuba Rivers

Site Number	Measured (mm)	Visually Estimated (mm)
South Yuba River		
2	39.0	80
4	58.2	60

TABLE 2
Measured and Visually Estimated Median Gravel Size at Selected Sites on the South and Middle Yuba Rivers

Site Number	Measured (mm)	Visually Estimated (mm)
6	28.5	15
38	39.7	90
41	21.6	22.5
42	6.6	12.5
53	39.0	50
53A	17.0	12.5
54	28.5	20
56	36.6	30
79	50.2	75
80	26.4	20
106	32.0	22.5
107A	46.8	30
119	74.3	80
120	32.0	35
121	21.7	20
148	24.7	17.5
148A	25.3	20
150	50.3	60
151	63.0	80
Middle Yuba River		
191A	64.0	110
192	28.3	40
228A	45.3	37.5
230	40.0	20
231	46.5	30
237	64.0	140
262	23.4	27.5
266	28.9	30
267	56.7	100
277	29.8	20
321	31.4	42.5
321A	21.6	30
322	30.8	70
346	24.6	22.5
347	40.0	40
349	34.7	40
365	51.5	50
366	21.4	25
367	23.2	27.5

TABLE 3
Observed Gravel Bed Permeability of Potential Spawning Gravels at Selected Sites on the South and Middle Yuba Rivers

Site ID	Mean Permeability (cm/hour)*	Minimum Permeability (cm/hour)*	Maximum Permeability (cm/hour)*
South Yuba River			
4	4,281	980	8,633
6	45,382	2,028	239,319
41	1,618	192	2,773
42	6,137	440	18,755
53A	2,937	1,320	6,038
54	4,110	1,870	7,350
79	49,991	3,393	140,494
80	32,578	1,151	87,394
106	25,367	2,850	105,325
119	1,318	1,180	1,455
120	2,958	741	5,596
121	6,059	2,099	20,376
148	131,206	9,636	248,567
148A	14,445	942	38,683
150	156,115	8,046	239,318
151	121,227	25,886	239,319
Middle Yuba River			
228A	43,015	2,363	222,283
230	116,569	4,416	231,881
231	157,903	6,531	231,881
262	40,648	4,489	194,564
266	43,297	2,359	151,743
277	90,299	4,069	222,283
321	11,839	1,386	49,024
321A	3,486	1,819	4,870
322	2,496	1,465	4,315
349	15,610	1,527	39,913
346	94,231	11,064	273,229
365	154,410	1,642	262,763
366	10,978	10,269	11,687
367	98,477	9,688	227,463

* Average, minimum and maximum values of 2 to 6 individual measurements at each site.

TABLE 4
Mean Water Depths and Velocities Over Potential Spawning Gravels at Selected Sites on the South and Middle Yuba Rivers

Site Number	Mean Depth (feet)*	Mean Velocity (feet per second)*
South Yuba River		
4	1.39	1.46
6	1.57	0.97
41	2.03	0.53
42	2.01	0.48
53A	1.61	0.93
54	1.68	0.99
79	1.06	0.75
80	1.62	0.55
106	1.84	0.88
119	1.53	0.74
120	2.00	0.50
121	1.40	0.64
148	1.94	0.74
148A	1.92	0.14
150	1.50	0.53
151	2.02	0.25
Middle Yuba River		
192	1.17	0.83
228A	1.21	1.63
230	1.39	1.14
231	1.48	1.23
237	1.81	1.12
262	0.85	1.07
266	1.08	0.43
277	1.45	0.72
321	1.35	1.04
321A	1.46	0.66
322	1.35	0.60
346	1.71	0.60
349	1.61	0.51
365	1.29	0.48
366	1.28	0.78
367	1.88	0.80

* Mean values of 4 to 6 individual measurements at each site.

The mean maximum depth of pools adjacent to potential spawning areas was 2 meters (6.6 feet) in the Middle Yuba River and 2.3 meters (7.4 feet) in the South Yuba River. The habitat study team judged the deepest pool adjacent to potential spawning habitat to be about

6.1 meters (20 feet) deep. Adjacent pool habitats would provide suitable refuge areas for spawning spring-run Chinook salmon (for example, less than 2.4 meters [8 feet] deep, or between 1.2 and 2.4 meters [4 and 8 feet] deep with cover) at 266 potential spawning sites (138, 117, and 11 in the South Yuba, Middle Yuba, and upper Yuba rivers, respectively). At 37 sites in the Middle Yuba and 23 sites in the South Yuba River, the maximum depth of the adjacent pool habitat was less than 1.2 meters (4 feet) or no cover was present and would not provide suitable refuge areas for spawning Chinook salmon; only steelhead are likely to use these spawning sites.

Habitat Quantity

The gravel beds at the pool tails were relatively small, with an average size of 79 square meters (m^2) (849 ft^2) in the South Yuba River and 93 m^2 (999 ft^2) in the Middle Yuba River. The largest site was over 1,500 m^2 (16,200 ft^2) and the smallest was 2.8 m^2 (30 ft^2), both of which were located in the lowermost reach of the South Yuba River. Overall, there was approximately 18,825 m^2 (202,630 ft^2) of potential spawning area in the Middle Yuba River, most of which is located upstream of Our House Dam. The South Yuba River contained about 16,165 m^2 (173,985 ft^2) of potential spawning area; only 1,195 m^2 (12,850 ft^2) of potential spawning area was found in the upper Yuba River below the mouth of the Middle Yuba River.

However, not all potential spawning sites had adjacent pool habitats that would provide suitable refuge areas for spawning Chinook salmon (such as, less than 2.4 meters [8 feet] deep or between 1.2 and 2.4 meters [4 to 8 feet] deep with cover). Excluding the potential spawning sites without suitable refuge areas, the total area of suitable spawning gravel for Chinook salmon in the South Yuba River is reduced to 14,222 m^2 (153,059 ft^2). Similarly, the total area of suitable spawning gravel for Chinook salmon in the Middle Yuba River is reduced to approximately 15,002 m^2 (161,473 ft^2) when excluding sites without suitable refuge areas. Total spawning area for steelhead was not adjusted because all potential spawning sites were assumed to have suitable refuge areas during the spawning period for steelhead.

At 9 of the 31 intensively surveyed sites, there was additional spawning-sized gravel on the floodplain adjacent to pool habitat that could be used by steelhead if inundated during high winter and spring stream flows. An average of 114.3 m^2 (1,230 ft^2) of additional spawning-sized gravel was located adjacent to the wetted channel at these sites; however, dense growths of willows made some of the additional gravel area unsuitable for spawning. This additional area was included in the calculation of potential steelhead redds at these sites.

Potential Number of Redds

There was a sufficient amount of gravel at each site to provide spawning habitat for at least one redd and up to about 589 Chinook salmon and 614 steelhead redds at the largest site. There was sufficient spawning habitat with suitably-sized gravel to support approximately 3,718 Chinook salmon redds and 3,646 steelhead redds in the Middle Yuba River (Figure 3). The South Yuba River could potentially support up to 3,991 Chinook salmon redds and 4,386 steelhead redds (Figure 4). Up to 287 Chinook salmon and 164 steelhead redds could potentially be supported in the upper Yuba River below the confluence of the North Yuba and Middle Yuba rivers. These estimates represent the maximum number of redds that could be supported by the available gravel area, taking into account the median gravel size, permeability, and the effects of superimposition.

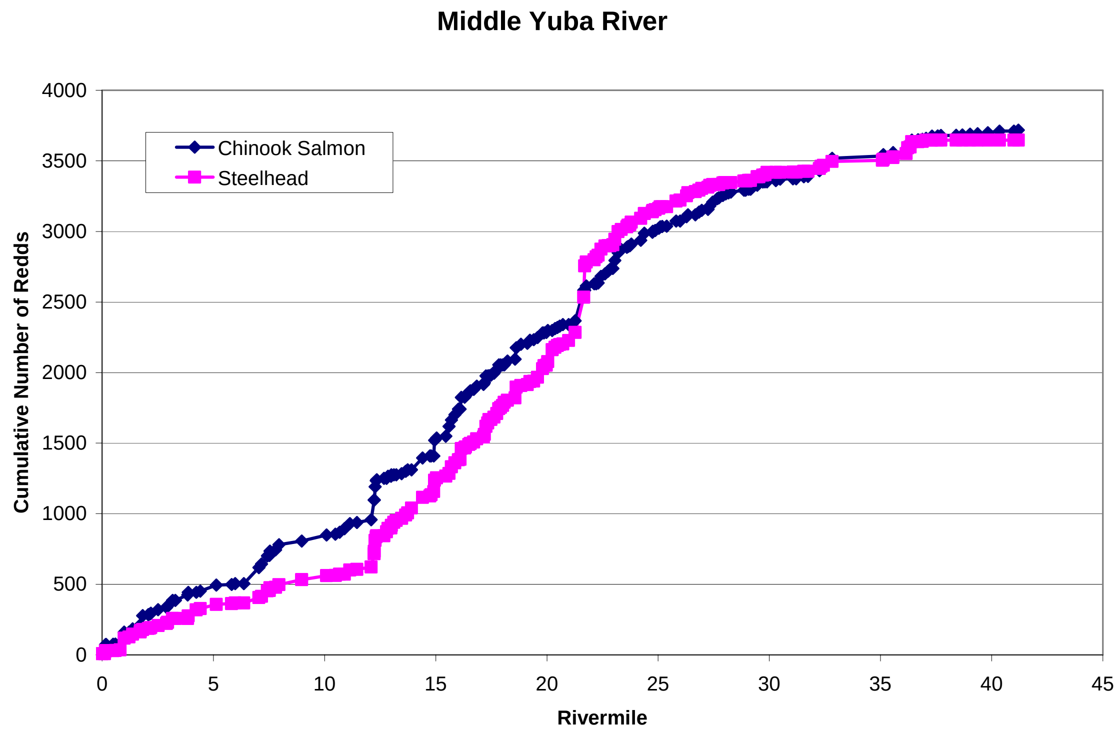

FIGURE 3
Cumulative Number of Potential Chinook Salmon and Steelhead Redds in the Middle Yuba River

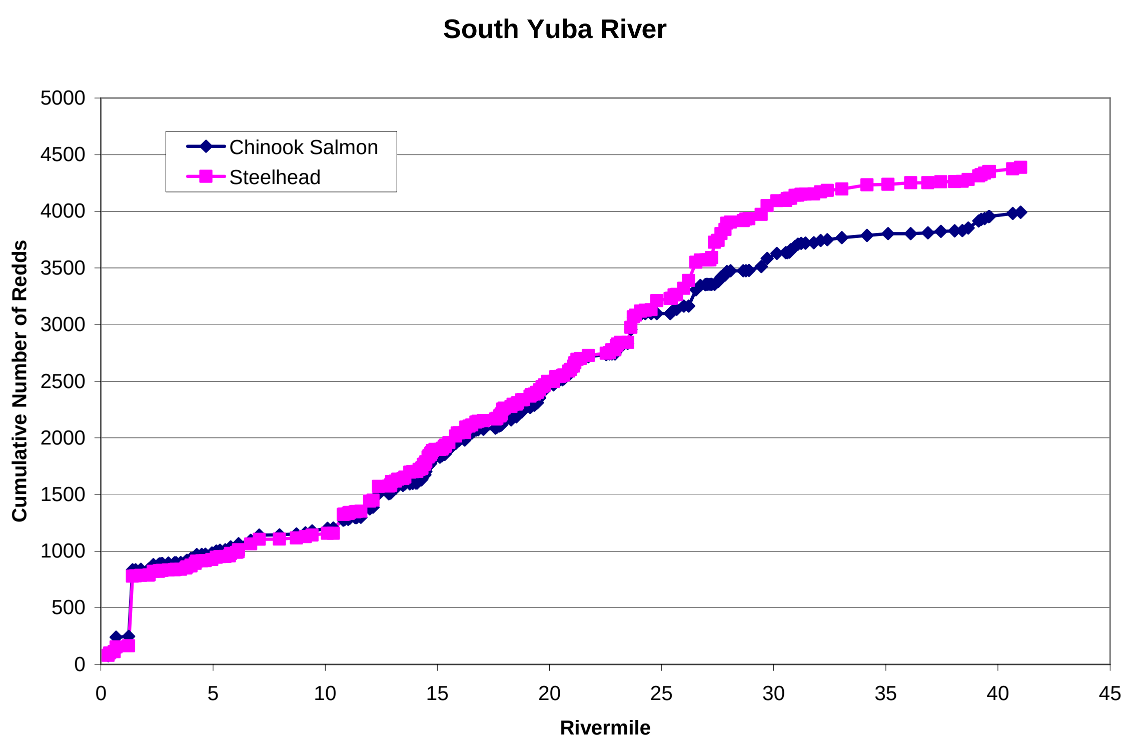

FIGURE 4
Cumulative Number of Potential Chinook Salmon and Steelhead Redds in the South Yuba River

Discussion

Timing of Field Surveys

The aerial video was conducted during the typical spawning period for spring-run Chinook salmon. Hence, the analysis of spawning area based on the video reflects flow conditions that would be expected to occur during the spawning period for spring-run Chinook salmon if they were introduced into the upper watershed. Steelhead, on the other hand, spawn during the winter and early spring when stream flows may be higher. No video or field studies were conducted during this time period. However, as described above, additional areas of suitably-sized gravel for spawning outside of the wetted channel were identified and quantified during the field surveys. This additional area was included in the calculation of potential redds.

Flows were approximately 30 cubic-feet-per-second (cfs) below Our House Dam on the Middle Yuba River (USGS 11408880) when the aerial video was flown in October 2002. Diversions into the Lohman Ridge tunnel above Our House Dam were negligible at this time, indicating that flows in the Middle Yuba River ranged from approximately 5 cfs below Milton Dam to the 40 cfs measured at Our House Dam. Flows were approximately 40 cfs at Jones Bar on the South Yuba River (USGS 11417500) in October 2002. The field surveys were conducted in July 2003 at flows of approximately 75 cfs in the Middle Yuba River above Our House Dam and 75 cfs at Jones Bar on the South Yuba River. Because flows were somewhat higher during the field surveys than when the aerial video was flown, the amount of potential spawning gravel in the wetted channel may have been overestimated during the field surveys and underestimated from the video. Overall, the differences in flows between the aerial video and the field surveys are likely within the range of flows that would occur with annual variation during the spawning period for spring-run Chinook salmon. Thus, the estimates of potential spawning area cannot be considered conservative. Habitat Quality

Spawning habitat was judged to be suitable for Chinook salmon and steelhead based on the gravel size, bed permeability, and the availability of adjacent refuge areas (deep pools providing cover). Pool habitats adjacent to potential spawning sites were judged to provide suitable refuge areas for spawning Chinook salmon at the majority (63 percent) of the potential spawning sites identified. The remainder of potential spawning sites identified did not have adjacent pool habitats deemed suitable as refuge areas for spawning Chinook salmon, because they were shallow (less than 8 feet deep) and lacked boulders, rock ledges, overhanging vegetation, and/or surface turbulence. Potential spawning areas without suitable refuge areas may still be used by Chinook salmon, but this use cannot be predicted or assumed. Therefore, the estimated number of potential redds that could be supported in the available habitat should be considered as conservative and the true number of redds could be higher. In regard to steelhead, all adjacent pools would likely provide adequate refuge habitat because spawning would occur during winter and spring when stream flows are typically high and pools are relatively deep, with extensive surface turbulence.

Both Chinook salmon and steelhead prefer to spawn in gravel with a median diameter of about 25 mm (1 inch), although they are capable of moving gravel with diameters of up to about 10 percent of their body length (Kondolf 2000). The majority of Chinook salmon use gravels with median diameters from 22 to 48 mm (0.9 to 1.9 inches) but will use gravels with median diameters from 11 to 78 mm (0.4 inches to 3.1 inches) (Kondolf and Wolman 1993).

Most steelhead spawn in gravels with median diameters from 18 to 33 mm (0.7 to 1.3 inches) but will use gravels with median diameters from 10 to 46 mm (0.4 to 1.8 inches) (Kondolf and Wolman 1993). Gravel depths of at least 15 mm (6 inches) are required for spawning. Most of the potential spawning sites in the upper Yuba River watershed had gravels within the size range typically used by salmon and steelhead. Only a few of the potential spawning sites had gravels that were too large to be used by steelhead. Gravel depths were typically greater than the minimum required for spawning.

Gravel permeability in both the Middle and South Yuba rivers is relatively high compared to typical values (2,000 to 8,000 cm/hour) observed in undisturbed, natural spawning gravel in the lower Stanislaus (CMC 2002a, 2002b) and Tuolumne rivers (Stillwater Sciences 2001). Salmonids in the Stanislaus River clean the gravel during redd construction and increase permeability to about 26,000 cm/hour (CMC 2002b). Laboratory studies indicate that the survival of Chinook salmon eggs to emergence would be 80 percent with a permeability of 26,000 cm/hour (McCuddin 1977). The relatively high values observed in the Middle and South Yuba rivers suggest that water flow through the gravels would be adequate to provide for high survival to emergence. However, if redd superimposition occurred, then fines cleaned from the superimposing redd could entomb alevins in the superimposed redd (CMC 2002b). Estimates of the number of redds that could be supported in the upper Yuba River watershed were adjusted to account for the effects of superimposition. Turbid intragravel flow during egg incubation can coat incubating eggs with silt and result in suffocation (CMC 2002a); this would primarily affect steelhead that spawn during winter and spring when high flows and storm runoff cause erosion and bed movement.

Based on habitat preference criteria developed for fall-run Chinook salmon in the Stanislaus River (Aceituno 1990), Chinook salmon prefer to spawn in water that is between 0.4 and 0.9 meters (1.3 and 3 feet) deep with velocities from 40 to 85 cm per second (1.3 to 2.8 feet per second). The mean water depth over the gravel beds at the 31 intensively studied sites was within the preferred depth range for spawning. The mean velocities were below the preferred range, but still provided relatively high rates of intra-gravel water flow measured as permeability. Flows higher or lower than observed during the field surveys would likely result in different flows and velocities over the potential spawning beds, but the exact relationship between flow and depth and velocity at each site remains unknown. However, given the broad range of depths and velocities considered suitable for Chinook salmon (Bjornn and Reiser 1991), depths and velocities at potential spawning sites in the Middle and South Yuba rivers are unlikely to be unsuitable for use by spring-run Chinook salmon within the flows anticipated under current water operations. Higher streamflows during winter and spring would likely provide suitable depths and velocities for spawning steelhead.

Habitat Quantity and Number of Redds

The estimates of potential spawning area and the number of redds that could be supported represent the area and number of Chinook salmon and steelhead redds that could be supported in the spawning areas identified during the surveys, and assume that there are no barriers that block access to potential spawning habitat and that stream flows and water temperatures are suitable at all sites during the spawning and incubation period. It also assumes that the identified potential spawning areas have suitable holding habitat for spring-run Chinook salmon nearby. The results of the barrier, holding pool, and water temperature analyses will be used in conjunction with the distribution of potential spawning sites to assess the total amount of suitable spawning habitat in the upper Yuba River watershed under current conditions.

Human Influences

Gold mining influenced the potential spawning habitat for salmonids at many sites in the Middle Yuba River. Suction dredges were being used to mine gold at almost every site accessible by foot, including most of the sites visited during the July 2003 field surveys. Miners typically remove, by hand, the overlying large cobbles from the substrate in a pool and then use a small suction dredge to pump gravel from the pool bottom where it is deposited onto the pool tail. These activities deepen the pools and increase the amount of spawning-sized gravel at the pool tail, potentially improving the quality of spawning gravel at the pool tail. Although dredging might improve spawning habitat, it could result in mortality of spring-run Chinook salmon and steelhead eggs and alevins if gravel disturbance occurs during the spawning and incubation period.

Human movement of rocks to deepen the pools for swimming and diving also may improve a substantial amount of spawning habitat on both the South Yuba and Middle Yuba rivers. Many sites contained evidence of the removal of large cobbles from the potential spawning areas to create 0.3 to 0.6 meter (1 to 2 foot) high weirs at the pool tail. Removing these cobbles exposed the underlying spawning-sized gravel, thereby reducing the median gravel size and improving the sites for spawning. However, the weirs may reduce the suitability of the sites for spawning by reducing the velocity of the water flowing over the gravel bed.

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